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Volume 7, Number 3 (March 1983)

The Solar Ocean Energy Liaison

SPECIAL FEATURE: OTEC AND FRESHWATER

Solar
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The OTEC Liaison

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DUTCH OTEC TO REPLACE OIL ON BALI

The Dutch firm of Delta Marine Consultants/Hollandische Beton Groep (DMC/HBG) has announced that an undisclosed amount of government funding has been committed for an OTEC project on the island of Bali, Indonesia. Investigations are also being conducted on Curacao in the Netherlands Antilles. According to Joseph R. Vadus of NOAA, who interviewed Dr. Bart Van der Pot, program manager at DMC, in December, the Bali project is going full-steam ahead with operation expected by early 1985, while the Curacao project is still in the planning stages. HBG (through DMC) is the prime contractor for the projects.

In a co-operative, cost-sharing program, the Netherlands Government recently agreed with oil-rich Indonesia to build a 500-kilowatt, land-based OTEC facility on Bali to replace a 400-kilowatt diesel generator providing 220-volt electricity for domestic use. This landmark project represents the first commercial OTEC facility in the world. The project is especially significant in that it will replace, not merely supplement, an oil-fired plant. In addition to its commercial function, the plant will be the largest demonstration of OTEC's ability to produce electricity yet to be undertaken. (The one-megawatt US OTEC-1 plant was designed only to test heat exchangers, not to produce power.)

Under the co-operative agreement, Indonesia will contribute to the project in the areas of site preparation, providing local facilities, and doing some of the construction work. The project plan is to conduct the site surveys (bottom mapping and temperature and current measurements) early this year. The design and engineering phase is scheduled to be completed by late 1983. Construction and installation of the facility are expected to take just over a year, and the plant will be ready for operation by late 1984 or early 1985.

The power plant will be a closed-cycle system, probably using the Trane Company's compact, aluminum shell-and-tube heat exchangers. Biofouling control will be both mechanical, using Amertap balls, and chemical, using chlorine. A five-year life cycle is anticipated for the heat exchangers.

The shelf-mounted, polyethylene cold-water pipe will be 1.8 meters in diameter and about 2500 meters long. Pipe sections will probably be manufactured in the Netherlands and shipped to Bali for deployment. The positively-buoyant pipe will be held in place by concrete blocks which will act as gravity anchors, keeping the pipe within about five meters of the bottom. Each concrete block will be attached to two points on the CWP by a synthetic line which runs through a sheave on the block. This configuration will permit the anchor system to accommodate any actual deviations from the calculated slope. The CWP will extend to a depth of 650 meters along a regular slope with a ratio of about 1 to 4, or 15 degrees, which is characterized by a layer of sediment overlying a volcanic-rock base.

At this time there are no plans for using the nutrients in the upwelled cold water or for producing freshwater, since Bali has

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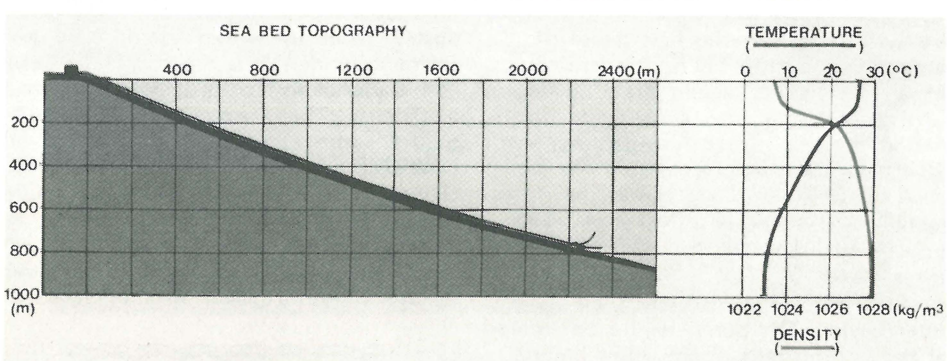

Figure 1. The slope of the seabed at the proposed OTEC site in Jamaica.

A PROPOSED IMW OTEC PLANT FOR JAMAICA

(Note: The following is the second in a series of articles on OTEC development in Jamaica.)

In 1981 an agreement was signed by the Petroleum Corporation of Jamaica (PCJ) and several Scandinavian firms, including SWECO, Alfa-Laval, and the Finnish company Oy Wiik and Hoglund AB, for the preliminary design of a one-megawatt OTEC pilot plant in Jamaica. The results of their work have been published in a brochure by SWECO and are summarized below.

Since the design of an OTEC facility is site-specific, the initial phase of the study involved selection of the optimum location for the plant. Two candidate sites were chosen from a number of possible locations, one suitable for a land-based plant and the other a submerged coral reef 750 meters offshore. The land-based option was finally selected, due to the prototypical nature of the project, the possibility that an aquaculture operation might be associated with the plant in the future, and the proximity to good roads and an existing power substation. Bottom mapping and current and temperature measurements were then conducted. The data were fed into the design process so that the entire facility could be cost-optimized for the specific location.

The slope of the seabed at the site is steep but regular, about 21 degrees, and the surface is characterized by rounded gravel at the upper part becoming more fine-grained with depth (see Figure 1). Tectonic activity in the region results in periodic slumping or sliding of the bottom sediments. In order to reach sufficiently cold water, the CWP would be 2450 meters long and extend to a depth of about 800 meters.

Due to the potential for slumping in the bottom sediments, and the fact that the pipe cannot be installed within very small tolerances in deep water, a flexible pipe was found to be desirable. A high-density polyethylene pipe was thus selected over steel or concrete. The pipe would be shipped to Jamaica in sections which would be welded into one long pipe. The welded joints would be reinforced with steel clamps.

(continued on Page 5)

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SOLAR OCEAN ENERGY

Editorial

L'EAU, ESSENCE DE LA VIE

Three-fourths of the Earth's surface is covered by water, yet only 1% of that water is available as freshwater, and most of that is unevenly distributed in large lakes. Clean freshwater supplies are reaching critical, life-threatening stages in many parts of the world. As this editorial is titled, water is the essence of life.

The World Health Organization estimates that by 1990 more than a billion people will have no reasonable access to potable water of acceptable quality. By the end of this century, the demand for water in more than 30 countries could exceed maximum sustainable supply. The World Bank estimates that an investment of up to \$800 billion will be needed if 100% access to adequate supplies of water for drinking and waste disposal is to be attained in the Third World alone by 1990. These estimates do not consider agricultural water needs, which constitute the largest freshwater demand sector, and which are at a critical level in many areas. Parts of the United States and its island territories face catastrophic futures in terms of water supply. Water shortages in the US in recent years have resulted in periodic, mandatory water-use bans in many (including coastal) regions, and have prompted the consideration or undertaking of numerous monumental water projects around the country. The future world-water-supply picture is so grim that the United Nations has proclaimed the 1980s the "Decade on Drinking Water and Sanitation".

If freshwater can be produced from seawater in large quantities and at lower prices using OTEC, the market for OTEC technology will be expanded considerably. This is a potential early market in locations where energy needs are small and are not expected to grow rapidly, but where water demand for agriculture and domestic use is already approaching or exceeding supply levels. From a humanitarian point of view, early commercialization of OTEC aimed primarily at freshwater production could play an important role in easing the water crisis and aiding the survival of millions of people around the world. In the light of this and the current energy surplus, perhaps Ocean Thermal Energy Conversion should be thought of as Ocean Thermal Water Conversion instead.

Philip E. Haring
Assistant Editor

BUDGET NEWS

DEPARTMENT OF ENERGY

The Department of Energy has submitted its OTEC spending plans under the continuing resolution for FY '83 to House and Senate Appropriations Committees. The total figure for the OTEC budget of \$14.5 million is broken down as follows: biofouling and corrosion research, \$1 million; heat-exchanger development, \$1.5 million; redeployment of the OTEC-1 cold-water pipe at the Natural Energy Laboratory of Hawaii, \$1.5 million; Phase II of the pilot-plant project, \$6 million; and other activities, \$0.5 million. The \$4 million deferred from FY '82 is also included, bringing the subtotal for Phase II to \$10 million. The announcement of whether there will be one or two awards for Phase II is expected by mid-May.

NOAA/OME

A NOAA reauthorization bill for FY '84 has been introduced by Congressman D'Amours (D-NH), chairman of the Subcommittee on Oceanography. The bill, which complies with the Administration's request, calls for a budget of \$470,000 for NOAA's Division of Ocean Minerals and Energy (OME), which represents a reduction of \$195,000 from the FY '83 budget. As reported in the January issue of OE, this sum was added to the FY '83 budget to enable the OME to conduct two OTEC-related environmental studies as part of its licensing function. A staff member of the Oceanography Subcommittee has indicated, however, that the funds for the environmental studies will probably be reinstated following hearings on the bill March 4th.

(continued from Page 1)
sufficient water supplies. In contrast, the primary purpose of the planned one-megawatt Curacao project would be to produce freshwater. In fact the first phase of this project would probably be the deployment of a CWP which would draw 15-degree Centigrade water into an existing desalination facility currently operating with 28-degree Centigrade water.

A land-based OTEC plant may be attached to the pipe at a later time. Preliminary indications are that the CWP will be three meters in diameter and will be constructed of a synthetic fabric such as polyester/kevlar. The pump would be located at the bottom of the pipe.

The news of the Bali project is yet another indication of the international race for leadership in the emerging OTEC industry. While the project is still fully government-funded, it is the first OTEC project undertaken to provide commercial electricity. The announcement and subsequent construction of the facility will benefit the entire OTEC community by providing an incentive for continuing commercialization efforts in the US, Japan, Scandinavia, and elsewhere. OE will keep readers up-to-date on the progress of this venture.

OPEN-CYCLE EVAPORATOR BREAKTHROUGH AT SERI

Researchers at the Solar Energy Research Institute (SERI) have developed an innovative method for facilitating the evaporation of the seawater working fluid in an open-cycle OTEC plant. This method has been demonstrated experimentally to yield, in a given volume and for a given liquid pumping power, heat-transfer rates about 70 times greater than some closed-cycle designs. The method, known as the vertical-spout evaporator, is based on a modification of a design invented by the Frenchman Leon Nisolle in the 1940s for the French OTEC project in Abidjan, Ivory Coast. Principal investigators on the SERI project were Terry Penny, Desikan Bharathan, and Frank Krieth.

The evaporator is simply a vertical pipe through which a stream of warm water is pumped upward, resembling a large water fountain. During evaporation, the stream of warm water sprays outward in all directions, resembling an "Afro" hair style. The photos show the performance of the evaporator in both non-evaporation and evaporation modes. This design is a vast improvement over the falling-jet evaporator discussed in the June 1982 issue of OE due to decreased parasitic-delivery losses and increased heat transfer.

A nominal, full-scale experimental vertical-spout evaporator (five inches in diameter), designed to produce steam flow equivalent to a 300-kilowatt heat rate, has undergone six months of testing at SERI with remarkable results. The heat-transfer coefficient was calculated from the experimental data and was scaled up to a one-megawatt thermal size. The results were

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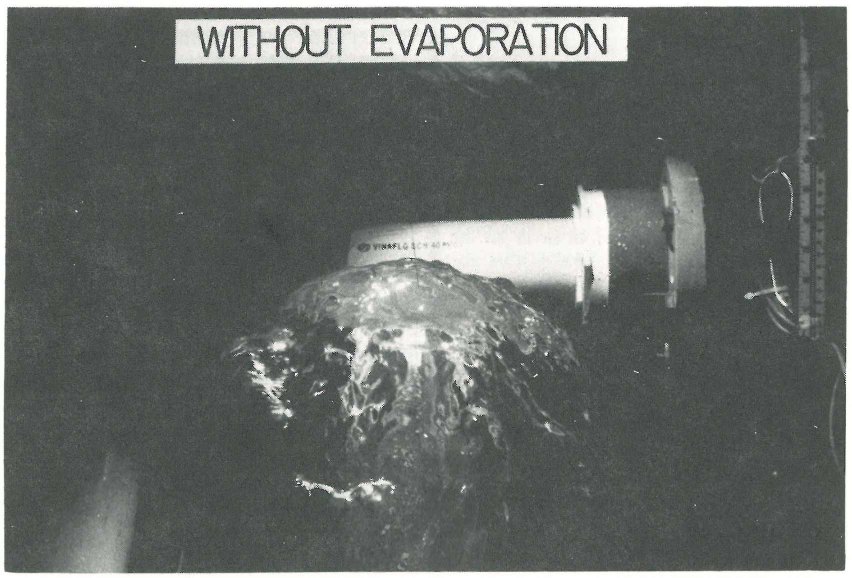

The vertical spout in non-evaporation and evaporation modes.

FRENCH EYE OTEC-BASED DESALINATION

Researchers at the French firm Alsthom-Atlantique have concluded a study comparing the cost of freshwater produced by a conventional oil-fired dual-purpose (electricity and desalination) plant with that produced by an open-cycle OTEC/desalination plant. The results indicate that the cost of freshwater is significantly less using the OTEC option.

An open-cycle OTEC plant which uses surface-contact condensers produces freshwater as a by-product of the electricity-production process. The French study notes that by a strange coincidence, an OTEC plant designed to satisfy the *power* requirements of a city in the tropics produces just about the right amount of freshwater to meet the *water* requirements of that city. The rate of production of the distillate is about 1500 cubic meters per day (almost 400,000 gallons per day: gpd) per megawatt of electricity output. This amounts to an average per-capita consumption of 100 liters (27 gallons) per day of water and 450 kilowatt-hours per year of electricity in the tropics, as compared with 150 liters (40 gallons) per day and 2300 kilowatt-hours per year in France.

A low-temperature desalination process recently developed by the French Atomic Energy Authority can produce 8,000 cubic meters (2.1 million gallons) per day per megawatt of electricity available from an OTEC plant. The new process makes possible the combining of an (energy-producing) OTEC plant with an (energy-consuming) desalination plant on a barge moored offshore. Using the new process, a production ratio of three kilowatt-hours per cubic meter (.0113 kilowatt-hours per gallon) of potable water can be obtained.

In the first phase of the French study, the researchers calculated the distillate-output and power-output capacities of a combined OTEC and desalination plant versus plant size. Plant size is characterized by the diameter of the cold-water pipe (CWP). At an available power of one megawatt of electricity, for example, an open-cycle OTEC plant with a two-meter (6.6-foot) CWP has a freshwater by-product of 1500 cubic meters per day (almost 400,000 gpd). When combined with the low-temperature desalination plant, the peak freshwater capacity is 10,000 cubic meters per day (2.64 million gpd) with zero exportable electricity output. Four megawatts of power, in addition to the 10,000 cubic meters per day of freshwater, could be exported from the plant if the CWP diameter were increased to 3.5 meters (11.5 feet). An open-cycle OTEC plant of this size operating alone would produce 5,000 cubic meters per day (1.32 million gpd) of freshwater as a by-product.

The second phase of the French study examined the cost of electricity versus the cost of oil in a conventional power plant. [Throughout this cost analysis a conversion

(continued on Page 5)

(continued from Page 3)
compared to five other OTEC evaporator designs on which experiments have already been conducted.

These other designs are: the aluminum, shell-and-tube, closed-cycle heat exchanger tested by Argonne National Laboratories; an advanced closed-cycle, compact heat exchanger developed by the Trane Company; the direct-contact (DC), falling-jet evaporator developed earlier at SERI (see the June 1982 issue of OE); the DC, falling-film evaporator; and the DC, falling-jet evaporator with screens for spray enhancement, both of which were also developed at SERI. The results of this comparison are summarized in Table 1. Column 1 indicates the flow rate necessary to produce vapor equivalent to a one-megawatt heat rate in the various design options in kilograms per second (kg/s). The vertical spout requires the smallest flow rate, indicating the highest efficiency and, conversely, the lowest value of parasitic losses to produce the same power potential. Column 2 shows the volumetric heat-transfer coefficient in kilowatts per cubic meter per degree Kelvin (kw/m^3/^{o}K). Column 3 is a "figure of merit" which indicates the heat transferred divided by parasitic losses times volume, in units of one per cubic meter (1/m^3). The inlet temperature for this analysis was 25^o Centigrade, typical of potential OTEC sites. Clearly, the vertical-spout evaporator represents a remarkable breakthrough in open-cycle system design. Direct-contact condenser studies are under way using the same design, with promising initial results.

Calculations were then made to compare two design options for the vertical-spout OTEC plant. One alternative is to maximize net power per unit of area of the facility platform, with a concurrent increase in parasitic losses due to the increased pumping requirements. The second option is to minimize parasitic losses, with the resultant loss in net power per unit of platform area. The results of these calculations indicate that when net power is maximized, parasitic losses reach 32.5% of the gross power output. (At present reliable data on demister performance under OTEC conditions are not available; suitable demister losses have not been accounted for.) Conversely, parasitic losses can be minimized to 22.4%, but this option requires an increase in platform size to obtain the same net power value. Up to 26 kilowatts per square meter of platform area can be obtained upon maximizing net power per unit of area, whereas only 15 kilowatts per square meter can be obtained when parasitic losses are minimized. (A steam velocity of 30 meters per second at the evaporator is assumed; the condenser loading is twice that of the evaporator.) This trade-off translates into higher initial capital costs (for a larger platform) if parasitic losses are to be minimized, versus lower initial capital costs, but higher operation costs (due to increased parasitic losses), if the net power per unit of area is to be maximized.

Researchers at SERI have also discovered that evaporator performance can be enhanced up to nearly 100% by injecting gas bubbles into the warm seawater. This implies that gas evolution in the spout may not be a problem and, in fact, may improve performance, as increases in the surface roughness due to biofouling could again increase the bubbling in the intake water and hence evaporation. However evolved gas drastically decreases condenser performance, and therefore must be exhausted from the vacuum chamber continuously. A trade-off study between these events is under way. Another problem associated with this system is droplet entrainment in the seawater vapor. SERI researchers are currently looking at several demisting schemes with low parasitic losses, and feel that a solution is attainable shortly with commercially-available hardware components.

Full details of the vertical-spout evaporator will be presented at the joint ASME-JSME Thermal Conference in Hawaii March 20th through 24th.

TABLE 1. Comparison of 1MW thermal Heat Exchanger Designs

HEAT EXCHANGER TYPE	REQUIRED WATER FLOW RATE (Kg/s)	VOLUMETRIC HEAT TRANSFER COEFFICIENT (kW/m^3/°K)	FIGURE OF MERIT (1/m^3)
Union Carbide Sprayed Bundle shell-and-tube[a] (closed cycle)	131	85	91
Trane Plate-Fin[b] (closed cycle)	264	159	302
SERI falling jet[c] (open cycle)	68	268	1042
SERI falling film[d] (open cycle)	53	555	1647
SERI falling jet with screens[e] (open cycle)	53	427	1670
SERI vertical spout[e] (open cycle)	49	1883	7086

[a] "OTEC-1 Power System Test Program: Performance of one-megawatt Heat Exchanger," ANL/OTEC-PS-10, November 1981;

[b] "OTEC Performance Tests of the Trane Plate-Fin Heat Exchanger," ANL/OTEC-PS-7, April 1981;

[c] "Measured Performance of Falling-Jet Evaporators," SERI/TP-631-1270, June 1981;

[d] "Design Methodology for Direct-Contact Falling-Film Evaporators and Condensers for Open-Cycle Ocean Thermal Energy Conversion,"SERI/SAI-083-83R, February 1982;

[e] Unpublished SERI data.

UPDATE ON HAWAII CONFERENCE: OTEC ROUND-TABLE

A round-table discussion focusing on OTEC has been scheduled for the joint ASME-JSME Thermal Conference to be held in Hawaii March 20th through 24th (see the February 1983 issue of OE). The discussion is scheduled to last three to four hours, and will cover a range of topics including pilot-plant development, open-cycle OTEC, advanced closed-cycle OTEC, and OTEC products such as fuels, chemicals, and freshwater. Representatives of both the US and Japanese OTEC communities will participate, making the round-table an excellent arena for exchanging information and for assessing the future of OTEC in both nations. The meeting is scheduled for 2:40 pm March 23rd. Participants are listed below.

Ben Shelpuk, SERI: Chairman
Frank Krieth, SERI: Vice-Chairman and Raporteur

From the US:
William Avery, Applied Physics Laboratory, Johns Hopkins University
John Craven, Marine Studies, University of Hawaii
Malcolm Jones, EBASCO
A.T. Wassel, Science Applications Incorporated
Jay Yaffo, Ocean Thermal Corporation

From Japan:
F. Itoh, Project Manager of the Nauru Test Facility
Dr. Mori, Tokyo Institute
M. Nagasaki, Tokyo Institute
Dr. Suzuki, Mitsui Engineering and Shipbuilding Company
H. Uehara, Saga University

(continued from Page 3)
rate of one French Franc (FF) = .182 US dollars was used.] The researchers assumed: capital cost of 7,000 FF ($1274) per kilowatt; cycle efficiency = 0.25 kilograms of oil per kilowatt-hour; plant duty factor = 0.90; interest rate = 10%; write-off time = 20 years; operating cost: only cost of oil considered. Under a range of oil costs from 600 FF ($109.2) to 1600 FF ($291.2) per ton of oil, the cost of electricity produced ranged from 0.26 FF to 0.51 FF (47.3 to 92.8 mills) per kilowatt-hour.

The next step in the study was the calculation of the cost of producing 10,000 cubic meters of freshwater daily in terms of the cost of oil using a conventional dual-purpose (power/desalination) plant. Gross energy production of the plant was optimized for each oil-cost value and, holding water output constant, there was a variable amount of exportable electricty after the production of the freshwater. (The desalination process requires 0.125 kilowatts per cubic meter, or 264.2 gallons, per day.) In the same (600 to 1600 FF per ton) range of oil costs, water costs ranged from 5.32 FF to 8.32 FF per cubic meter (3.6 to 5.7 mills per gallon). An exportable surplus of electricity resulted, ranging from 7450 kilowatts (at the lowest oil cost) to 4050 kilowatts (at the highest oil cost).

The next phase was the calculation of the cost of freshwater produced by a combined open-cycle OTEC/desalination plant. Three sizes of OTEC plants, characterized by CWP diameters of 2, 2.8, and 3.5 meters (6.6, 9.2, and 11.5 feet) were examined. With an output of 10,000 cubic meters per day held constant, desalination-plant size (thus cost) decreased in proportion to increasing OTEC-plant size (cost), due to increased freshwater by-product at larger sizes. Conversely, the electricity available for export increased with increasing plant size, due to the reduction in desalination-plant power requirements.

The cost of OTEC-produced freshwater was calculated on the basis of an electricity credit method at two oil-cost levels (800 and 1600 FF per ton, or $145.6 and $291.2 per ton). In other words, the surplus electricity would be sold at an oil-based electricity production price and credited to repayment of the cost of the dual-purpose plant spread over a 20-year write-off period at a 10% interest rate. With a two-meter-diameter-CWP OTEC plant, 1,000 kilowatts of net electricity is produced along with the 1500 cubic meters per day of freshwater. All the net electricity is consumed by the desalination plant to meet the water requirement of 10,000 cubic meters per day, and thus there is no exportable electricity credit. As a result the freshwater cost is the same, 4.46 FF per cubic meter (3.1 mills per gallon) at both high and low oil costs.

When the CWP diameter is increased to 2.8 meters, net OTEC power and freshwater by-product increase, while desalination-plant power requirements decrease. Consequently, 1200 kilowatts of electricity is available for export. Deducting this income (calculated on the basis of oil-produced electricity at the two oil-cost levels) from the capital cost of the combined plant, the cost of freshwater is determined to be 4.37 FF and 3.94 FF per cubic meter (3.0 and 2.7 mills per gallon) at the low and high oil costs respectively over the life of the plant.

When the diameter of the CWP is set at 3.5 meters, a larger freshwater by-product results and the desalination-plant size decreases, keeping gross freshwater output constant. In addition, 4,000 kilowatts of electricity is available for export. However the capital costs of the larger OTEC plant increase faster than the decrease in desalination plant costs; therefore at the lower oil-based electricity price, the freshwater cost is higher (5.02 FF per cubic meter, or 3.5 mills per gallon) than the 2.8-meter-CWP level. At the higher oil-based electricity price, the freshwater cost is far lower (3.58 FF per cubic meter, or 3.5 mills per gallon) than the other options due to the greater amount of exportable electricity credited to the system.

When the cost of producing freshwater by conventional means is compared with that of using a combined open-cycle/desalination plant, the results are very favorable for OTEC. For example, at an oil cost of 140 FF per ton ($254.8 per ton) conventional desalination yields distillate at 8 FF per cubic meter (5.5 mills per gallon) with 5 megawatts of exportable power. For the same situation and the same exportable power, the OTEC scheme yields a distillate cost of less than 4 FF per cubic meter (2.75 mills per gallon).

Further studies are now planned for freshwater output in the range of 100 to 1,000 cubic meters per day (26,000 to 260,000 gpd). If the OTEC option retains its advantage at these lower outputs, the range of application of OTEC will broaden considerably.

BATTELLE TO STUDY ALTERNATIVE ENERGY TECHNOLOGIES

A study to help electric-utility personnel evaluate and plan conventional and alternative electricity-generation technologies is being proposed by the private, independent Battelle-Columbus Laboratories.

Researchers will evaluate the technical and economic viability of 14 alternative technologies, including OTEC. The analysis will allow individual utilities to conduct site-specific comparisons between these alternative and conventional generation technologies from 1980 through 2000.

"Typically," says Jere Bates, who heads the Battelle study team, "utilities have given some consideration to alternative technologies . . . however they frequently lack the resources to make an in-depth and up-to-date comparative study of the numerous options. Frequently the data available are not consistent, so that valid economic comparisons across technologies cannot be made." With each utility contributing a relatively small amount to the project, participating companies will receive the benefits of a large, comprehensive study without a large investment.

For utility personnel facing the issue of alternative technologies in planning and regulatory proceedings, the proposed study will provide: an objective, credible opinion and review, intended for use in regulatory proceedings, of the technical availability of 14 of the most prominent alternative generation technologies currently being discussed; data for assessing the cost-effectiveness of alternative generation technologies, both for decisions currently being made and for historic comparisons to justify prior decisions in regulatory proceedings; an "apples to apples" economic comparison of technologies, since each will be developed under a common methodology and set of assumptions; parametric analyses that allow electric-utility personnel to input site-specific characteristics, thereby determining the conditions under which each alternative technology will become cost-effective; and a description of the environmental, institutional, reliability, and system-planning issues associated with each technology.

Questions to be asked in the study include: Will the technology be commercially available to allow production by the year 1985 or 1995? Can the technology fit the operating characteristics of a utility? Will the technology fit into siting and construction constraints? Can the technology fit the operational planning requirements of the utility? Will the economics of the technology be competitive? Is energy-source availability during the life of the facility a concern? Will institutional considerations be a barrier to implementation? Will environmental considerations pose an obstacle to implementation?

Participation in this program will benefit electric utilities in that they can draw upon an unbiased evaluation in regulatory proceedings, will have a uniform basis on which to compare the economics of each alternative generation technology, and can quickly identify in detail the advantages and disadvantages of each system.

The output of this program will be a detailed set of individual generation technology reports with consistently-developed data allowing utilities to conduct site-specific comparisons, plus a number of useful charts comparing economics and system characteristics across technologies.

The program is scheduled to be completed in six months after a sufficient number of participants have joined in. Membership is available to interested companies for $9,500. For more information contact Jere Bates, Battelle-Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201, (614) 424-6499.

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Since the pipe is positively buoyant, heavy loadings, up to 30% of displacement, would have to be applied in shallow water to achieve sufficient stability to resist wave action. The design calls for concrete weights to be placed at three-meter intervals along the pipe. These weights will also keep the pipe off the bottom and act as stiffeners. As the pipe extends into deeper water, the problem of wave action becomes less significant; thus the loading will be reduced to about 10% of displacement, and steel weights, spaced farther apart, will be used. The wider spacing will also permit overbridging slumps and irregularities in the bottom topography without the risk of bending failure (see Figure 2).

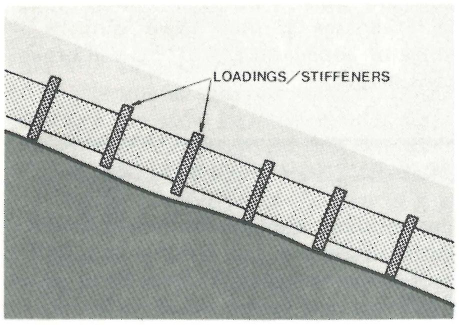

Figure 2. The CWP, showing stiffeners, overbridging a slump.

Installation of the pipe involves floating the entire length, filled with air, from its assembly site. A wire line attached to the offshore end would be pulled by a tugboat. By letting water in at the shore end and air out of the offshore end, the pipe will gradually sink from shore seaward (see Figure 3). To prevent the radius of the curvature from becoming too small during this operation, an axial force would be applied by the tug pulling on the line. Pipe deployment could be reversed at any time by refilling the pipe with air.

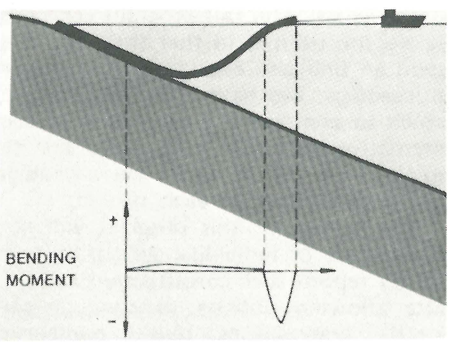

Figure 3. CWP deployment.

The length of the warm-water pipe is determined by the distance required to reach a sufficient depth to avoid air suction. This was found to be around 100 meters from shore. The discharge pipes must extend far enough offshore to avoid recirculation (about 150 meters).

The offshore end of the warm-water pipe would be screened to prevent entrapment of fish and large debris. Secondary, two-stage screening would also be performed by a rake screen and a traveling-band screen at the plant end. Debris would be channeled back to the sea.

The warm- and cold-water pipes would be connected to sumps which would be covered to eliminate light and thereby reduce biological growth. Both sumps would be equipped with four pumps, one for each heat exchanger, to minimize pressure drops and equalize water distribution.

The preliminary design calls for four evaporators and four condensers with titanium heat-transfer surfaces. Biofouling would probably be controlled primarily via chlorination and mechanical means (see the February 1983 issue of OE). The ammonia working fluid would flow vertically through the heat exchangers, upward in the evaporators and downward in the condensers. The condensate-storage tank is located at the lowest point in the cycle so that the ammonia would collect there during system down-periods.

PLANT CHARACTERISTICS

Thermal load		62 MW
Electricity output, gross		1.58 MW
Electricity output, net		1.00 MW
Warm water:	Flow rate	3.9 m^3/s
	Temp. in	27.5 °C
	Pipe dia.	1.6 m
	Pipe length	100 m
Cold water:	Flow rate	3.0 m^3/s
	Temp. in	6.2 °C
	Pipe dia.	1.6 m
	Pipe length	2450 m
Temperature difference		21.3 °C
Net efficiency		1.6 %

Table 1. Design parameters of SWECO's proposed one-megawatt OTEC plant.

All normal plant operations would be automatically controlled, while start-up, shut-down, purging, and refilling would be manually controlled. Power generation would be via a single-stage, high-pressure vapor turbine with a gearbox generator set.

The system described above and summarized in Table 1 is the preliminary design by SWECO for a prototype one-megawatt OTEC plant for Jamaica. The PCJ, which is linked to the Ministry of Mining and Energy, is currently evaluating several proposals from SWECO and at least two American firms for the detailed design and construction of Jamaica's first OTEC plant. Funding sources for this phase have not yet been identified. The next article in this series will examine the other design proposals and possible financing options pending release of that information.

OCEANS '83 UPDATE

Readers interested in learning more about international OTEC activities should definitely plan on attending the OCEANS '83 Conference to be held in San Francisco August 30th through September 1st. According to Joseph Vadus of NOAA, who will be heading the section, abstracts have already been submitted by Soviet and Swedish authors, and invitations have been sent to Dutch, French, and Japanese OTEC groups, with their attendance expected. The Soviet paper will cover their investigations into OTEC for Arctic regions, and the Swedish paper will discuss their OTEC activities in Jamaica. In addition, commitments to participate have been made by GE and the Ocean Thermal Corporation, the US pilot-plant project contractors. OE will continue to monitor the progress of this session as the Conference approaches.

A WORD ABOUT SWECO

SWECO is a consortium of Swedish consulting firms working in the areas of engineering, architecture, and economics. The consortium is a private, joint-stock company owned entirely by its five partner firms. SWECO was formed in 1960 when a number of experienced Swedish consulting firms decided to join forces to market their services abroad. Over the last 20 years, commissions have been carried out in more than 60 countries, and SWECO is generally active in 20 to 25 countries during any single year. SWECO's staff numbers more more than 2300 individuals, of whom 2,000 are technical personnel.

The consortium has been active in a broad range of projects, reflecting the expertise of the member firms. Its fields of activity include agriculture and agro-industry, environment, industrial development, community planning and development, transportation, water supply and sanitation, and energy. Within the energy category, SWECO is involved in hydropower, nuclear energy, offshore oil and gas, conventional electricity production and transmission, geothermal energy, wind energy, tidal power, solar energy, and OTEC.

The scope of services SWECO offers covers the entire range from strategic planning to implementation and operation of facilities. SWECO may be involved in any or all phases of a particular project, including: technology assessment; cost-benefit analysis; development studies and forecasts; site surveys; model and laboratory tests; technical assistance for financing; preparation of contract documents and specifications; detailed design; contract administration; supervision of construction, inspection, and testing; training of personnel; and systems operation and maintenance. This extensive capability enables SWECO to initiate, conduct, and complete its projects in a co-ordinated and efficient manner.

Further information can be obtained from the Public Relations Office, SWECO, Linnegatan 2, PO Box 5038, S-102 41, Stockholm, Sweden.

OTEC-1 CWP REDEPLOYMENT SCHEDULED IN JUNE

The OTEC-1 cold-water pipe (CWP), which was recovered last October (see the January 1983 issue of OE), is scheduled for redeployment in June at the Natural Energy Laboratory of Hawaii (NELH, formerly the Seacoast Test Facility). The 2200-foot-long pipe, which now consists of three 48-inch-diameter pipes clamped together, will be reconfigured into one pipe about 6,000 feet long so that it can extend from the land-based test facility to the cold-water resource offshore.

According to Tom Daniel, Director of NELH, the reconfiguration and redeployment are being financed by both state and Federal funds. An initial study by the Dillingham Corporation of Hawaii estimated that the process would cost $1 million. When the CWP was recovered, the Government of Hawaii offered to relieve the US Department of Energy (DOE) of the problem of disposing of the pipe if DOE would give the pipe and $600,000 to the State. Hawaii would contribute the remaining $400,000 to facilitate redeployment at NELH. The arrangement was approved and the funds were allocated, with the Federal funds coming through the Solar Energy Research Institute (SERI).

However a re-evaluation by Dillingham revealed that the project would actually cost $1.25 million, and DOE subsequently allocated another $100,000. The State of Hawaii is now in the process of raising the remaining $150,000.

A preliminary design review indicated that redeployment would be feasible. The final review is scheduled for March 14th in Hawaii. The pipe would be deployed in a manner similar to that used for the existing 12-inch pipe.

The existing CWP has been inspected via a submersible dive and found to be in good shape. The pipe extends about 6,000 feet from shore to a depth of 1,925 feet. The bottom of the pipe is 70 feet off the seafloor. Since the pipe was never intended to be permanent, however, the bottom mounting in the near-shore area and the landfall of the pipe were not designed to withstand major storm events. As a result, some damage has been incurred by the supports during the severe winter sea conditions. In addition, the submersible pump, which is located in 30 feet of water about 100 feet from shore, has already been rendered inoperable during some periods this winter. Witnesses report waves breaking at the site in 60 feet of water!

These environmental conditions establish rugged design parameters for a permanently-deployed CWP. The redeployment of the OTEC-1 CWP discussed so far in this article would only bring the pipe to within 50 feet of the surface. The near-shore and landfall deployment are an entirely different, and much more difficult, project. Moreover, to use the cold-water pipe in an OTEC operation, a pump station, a warm-water pipe, and a mixed-discharge pipe would have to be constructed.

Argonne National Laboratories (ANL) has been assigned by SERI the sub-task of outlining the various options for bringing the pipe ashore and for the other pipe and pump components. Among the options being considered for the CWP is embedding the pipe in a trench in the shallow portion of the seafloor and tunneling through the soft lava cliffs at the shoreline to avoid placing any portion of the pipe in the surf zone. This option would be costly, and there are a number of environmental considerations. At the March 14th review, ANL will present their ideas to NELH, who will contract a cost-evaluation study of this option. Apparently the $1.5 million appropriated in the FY '83 budget for CWP deployment (see the budget article in this issue) is to cover the cost of bringing the pipe ashore, as funds for the offshore deployment have already been allocated. Whether this will be sufficient to cover the cost of the operation has not yet been established.

Several projects have been suggested to NELH for using the cold-water resource made available through the CWP. These include a proposal by ANL for a closed-cycle system which would use other components from OTEC-1 and would supply power to NELH, with any surplus transmitted to the grid. The output would be in the range of 700 to 800 kilowatts net.

A second proposal is for an advanced conversion and power-delivery plan suggested by DOE and SERI. This would involve a five-year program of development and deployment of an open-cycle system which would ultimately put electricity into the utility grid system. The project would depend on Federal support, and thus open cycle, a technology not as developed as closed cycle, would be preferred.

A third proposal, for which the 48-inch CWP is not prerequisite, and for which $200,000 has been appropriated by the State of Hawaii for detailed design, is for a solar-pond OTEC (SPOTEC) plant. The project would include a one-acre demonstration pond and could use water from the existing CWP. The predicted output would be 28 kilowatts firm (minimum at all times). The $200,000 will also be used to construct a two-acre evaporation pond to provide salt for SPOTEC, though additional salt will have to be imported. Also funded by the $200,000 is a conceptual design of a 20-acre SPOTEC plant which would produce 300 to 400 kilowatts—enough to power both NELH and the adjacent Keahole Point Airport. Prime contractor for the SPOTEC project is SETS Incorporated, a Hawaii-based consulting firm.

The aquaculture projects at NELH reported in the September 1982 issue of OE are all proceeding well. Since the primary function of NELH is that of an energy laboratory, all experiments must be somehow related to energy. This connection is made through the use of nutrient-rich cold water upwelled for OTEC projects. Attendees at the joint Thermal Conference in Hawaii later this month will have an opportunity to visit NELH.

CURRENT/TIDAL-ENERGY CONVERSION RESEARCH IN AUSTRALIA

An innovative current/tidal-energy conversion system has been developed and tested by Dr. D. J. Hilton of the South Australia Institute of Technology. The concept differs from other current- and tidal-energy converters in that it uses a vertical-axis turbine instead of the traditional ducted, horizontal-axis turbine.

Tidal-energy systems usually rely on the construction of a barrage to present a pressure head to the turbine with unequal water levels on each side, limiting the number of sites where such a project is feasible. Since the potential energy is of a relatively low density, these turbines must also be of a large size in order to extract a significant amount of power. The vertical-axis turbine is of a simpler design and does not require the construction of a flow barrier to create a pressure head, thus representing a suitable alternative since it is less costly to construct and can be sited in many more locations.

The vertical-axis, Darrieus rotor has been used for several years as a wind turbine. To overcome centrifugal bending stresses under high winds, the turbines usually have an "eggbeater" configuration where the ends of the blades converge on the vertical axis. However when applied to water flows of comparatively low speed centrifugal stress is not a problem, and thus the turbine blades can be straight for greater energy-extraction efficiency.

Initial Australian research into the vertical-axis, water-flow turbine consisted of computer modeling. A single-streamtube and a multiple-streamtube prediction model were used. The two models differ in that the first assumes a uniform current velocity across the turbine's sweep area, while the latter assumes variable current velocities.

The second phase of the research consisted of model testing in a towing tank. This proved to be insufficient, however, because in order to achieve a realistic Reynolds number the water-flow speeds had to be increased, resulting in blade flexing. Thus a larger model, three meters in diameter, was constructed and deployed in a shipping channel.

For the "at-sea" tests the turbine was mounted on a flat-bottomed outboard motorboat in such a way that it could be raised and lowered (see photo). The turbine blades were made of steel-reinforced GRP (glass-reinforced plastic), and the rotor arms were made of tubular steel with GRP fairings. Initially, tests were conduct-

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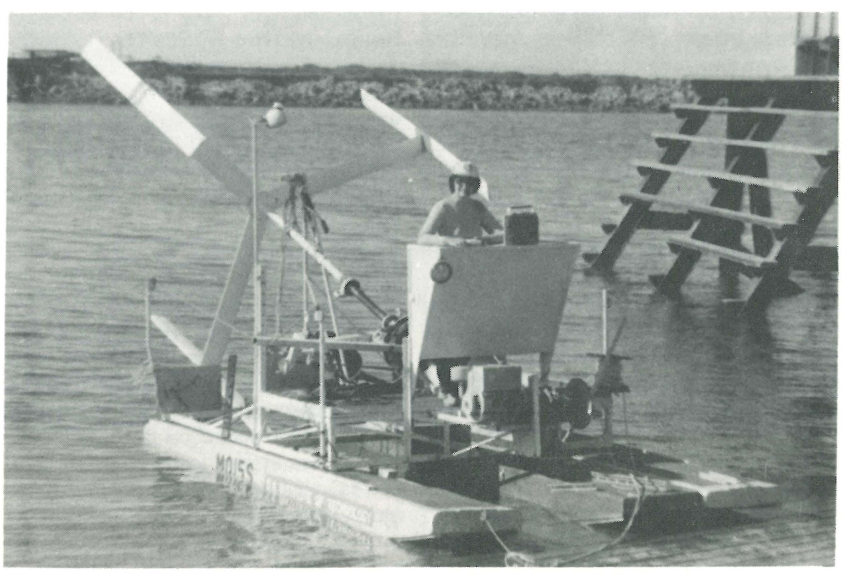
(continued from Page 7)
ed by propelling the entire system through the water with the outboard motor. A second series of tests involved pulling the boat by a line attached to a winch. Both three-bladed and four-bladed turbines were tested.

The power coefficient relative to the theoretical maximum was determined and compared with those calculated by the computer models. The three-bladed turbine produced a power coefficient of 0.52, very close to that predicted by the computer models. The four-bladed turbine did not perform as well as predicted, producing a power-coefficient peak of only 0.42. The three-bladed turbine, however, showed a greater tendency to stall at lower stream speeds. Except for the stall problem, the three-bladed turbine showed better overall performance characteristics than the four-bladed design.

Generally, the straight-bladed Darrieus turbine is a concept which allows considerable flexibility in configuration. The rotor-aspect ratio (blade length to rotor diameter) can be varied to suit particular site characteristics. The entire structure could be mounted on platforms affixed to the seafloor, or attached to anchored pontoons. For tidal applications, as opposed to current-energy conversion, a programmed start-up would be necessary at the onset of each tidal run; but this should not be a problem in the case of a system used to generate electricity. The speed variation occurring over a tidal cycle would also necessitate a variable-speed transmission for AC generation, but in any case DC transmission to shore could be selected if the distance offshore were significant.

While still in the early stages of development, this concept may eventually provide the mechanism for tidal- and current-energy conversion in a greater number of locations than are currently feasible with existing technology.



The experimental, vertical-axis water turbine tested in Australia, in the non-operational, raised position.

OEC LOBBYING GETS RESULTS

Through the efforts of the Ocean Energy Council (OEC), OTEC continues to receive support in the minds and actions of Congress and the Administration. OEC lobbying in recent months has produced several favorable results.

In the House, the OEC was successful in securing House Report language allocating $10.5 million (under the Continuing Resolution for FY '83) to OTEC complete with line-item project priorities (see the budget article in this issue). In addition, their efforts resulted in an on-the-record exchange between Messrs. Akaka and Bevill wherein Mr. Bevill states that under the Continuing Resolution the House "would expect the Department (of Energy) to proceed with funding at least at the level specified in the House Report".

In the Senate, the OEC lobbied successfully for Senate Report language allocating $11 million to OTEC and expressly providing that this amount include $7 million for two OTEC pilot-plant designs. In addition, OEC efforts were instrumental in securing on the record an intense exchange between Secretary of Energy Hodel and Senator Matsunaga during the Secretary's confirmation hearing. The Senator directly solicited Mr. Hodel's commitment to the OTEC program (see the January 1983 issue of OE). In connection with the Hodel confirmation hearings, Senator Matsunaga submitted to Secretary Hodel a written question prepared by the OEC which aimed at garnering support for two pilot plants.

In other areas, the OEC has been actively supporting proposed legislation which would extend the energy tax credits for all OTEC projects through 1995, and would increase the level of the OTEC energy tax credit to 20% from the current 15%.

A third area of OTEC activity is in the NOAA reauthorization hearings scheduled for March 4th. OEC representatives will be testifying at those hearings in favor of maintaining the increases in the FY '83 budget through FY '84. These additional funds (see the budget article in this issue) were taken out of the 1984 budget at the request of the Administration, but the work for which they were earmarked is not yet complete.

The OEC is the only organized, official voice of the OTEC community in Washington. They continue to seek support from corporations and individuals who benefit from their activities. Membership information can be obtained from Bob Scott, Gibbs & Cox Incorporated, 1235 Jefferson Davis Highway, Suite 700, Crystal Gateway 1, Arlington, Virginia 22202, (703) 979-1240.

US GOVERNMENT PROCUREMENT INVITATIONS AND CONTRACT AWARDS

Listed below are procurement invitations and contract awards related to OTEC in particular and ocean resources in general culled from the Commerce Business Daily. This is not to be construed, however, as a complete list.

Jan 31: Acoustic Research and Applications of Remotely-Sensored Data for Fishery and Oceanographic Investigations: Contract NA-83-FA-C-0007, $150,020, has been awarded to the Charles Stark Draper Laboratory Incorporated, Cambridge, Massachusetts. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Region, 14 Elm Street, Gloucester, Massachusetts 01930-3799.

Feb 11: Geologic Investigations and Resource Development Impact Assessment of Deep-Basin and Alternative Energy Resources in Louisiana: A proposers' conference will be held at 2 pm March 10th, 1983 at the Mineral Board Hearing Room, 1st Floor, Land and Natural Resources Building, 625 North 4th Street, Baton Rouge, Louisiana. Proposals, due March 29th, will be evaluated according to criteria defined in the RFP, and all proposers will be notified by mail of any contract awarded after such evaluation within 30 days of the closing date. Louisiana Department of Natural Resources, Post Office Box 44396, Baton Rouge, Louisiana 70804, Attention Janet A. Smith, (504) 342-6769.

Feb 15: Lecture Series on Energy Conversion to Be Held at DOE's Morgantown Energy Technology Center: Negotiations are being conducted on a sole-source basis with Professor Charles Backus, ASU Center for Research, Tempe, Arizona 85287. US Department of Energy, Morgantown Energy Technology Center, Box 880, Morgantown, West Virginia 26505, Attention John W. White, (304) 291-4317.